by Don Lancaster

Some Energy Fundamentals

There was a recent newsgroup flap over an individual who thought he was going to find an old solar panel scunging away at a yard sale somewhere, build up an electrolysizer out of scrap parts he had lying around, and then hydrogen power his *Cadillac Escalade* SUV by using "free" energy. Thus screwing the oil companies. What's wrong with this picture?

Or, for that matter, "not even wrong"?

There seems to be an amazing amount of appallingly bad misinformation on both traditional and alternate energy out there. Driven by everything from wishful thinking to hidden agendas to hero worship to big business hatred to government stupidity to subsidy ripoffs to bad labwork to utter cluelessness to R&D funding grabs to outright scams.

On the other hand, there are genuine new energy and alternate energy opportunities emerging that you just may be able to participate in and profitably tap. *Provided that you do thoroughly understand and work well within the underlying physical, thermodynamic, economic, engineering, and math principles that are ~certain~ to dictate what will and will not come down.*

I've gone over some of what follows on my *Guru's Lair* website, especially on our *Tech Musings* and *Hydrogen Energy* and *InfoPack* library pages. As an information gathering review, let us once again go over a few energy basics and see where they do and do not lead us...

Work, Power, and Energy

A *force* is something that pushes against something else. Such as gravity. Should it succeed, *work* gets done. If a one pound weight is lifted one foot, then one *foot-pound* of work has been done *on* the weight itself. Should the one pound weight be dropped by one foot, then work gets done *by* the weight.

Contrary to popular belief, *zero* work is done when a magnet is sitting on a refrigerator door. Yes, it will need *applied* work to remove the magnet. And yes, the magnet *delivers* work when replaced. *Both force and distance are needed before work gets done.*

Energy is just the capacity to do work. Or the ability to employ a force that moves something through a distance. Or performs some exact electrical, thermal, chemical, or whatever equivalent to mechanical work.

Power is the time rate of doing work. Thus, *energy* is *"how much"* and *power* is *"how fast"*.

One older unit of energy measurement is the BTU, or the *British Thermal Unit* This is the amount of heat energy needed to raise the temperature of one pound of liquid water by one degree Fahrenheit.

Or roughly the energy in one large kitchen match.

Better and newer units of power and energy have been electrically defined. If you apply a voltage (a form of force) of one volt to a resistance of one Ohm, a current of one Ampere results, and the resistance dissipates a heat power of one *Watt*. A typical flashlight outputs about one Watt of combined light and (mostly) heat energy. And 746 such Watts represent one Horsepower. A thousand Watts is a kilowatt, and a million watts is a megawatt.

One Watt of power present for one second represents an energy quantity of one *Watt-second*, and otherwise called a *Joule* We also have larger kilojoules, megajoules, and gigajoules. But most people don't have the foggiest notion how big a gigajoule is. Why, they do not even know what color a gigajoule is or are even able to visualize its lateral imminence. Instead, I very much prefer to use an energy unit called a *watt hour*. Or its larger kilowatt hour and megawatt hour buddies.

Let's see. Because a Joule is one watt second, there are apparently 3600 Joules in one watt hour. Watt hours are easily visualized by just about anybody. A kilowatt hour is consumed by running a 100 watt light bulb for ten hours. A microwave oven draws about one kilowatt hour in one hour of operation, or about a week's normal use.

A solar powered calculator consumes about one watt hour of energy over its actual use lifetime.

Running up stairs as fast as a fit person normally does uses about 200 Watts or just under a quarter horsepower. Doing so continuously for five hours expends a kilowatt hour of energy. Or ten cents worth of retail grid electricity.

There are 3412 BTU's in a kilowatt hour. As per this rather handy *converter*.

One sure sign of web idiocy is when power and energy units get mixed up, confused, or misapplied. I'd be most happy to sell you a device that gives you a hundred watts back out for every watt you put in.

So will *Radio Shack*. It is called a *capacitor*.

Sources, Carriers, and Sinks

After such temporary distortions as subsidies and taxes are removed, our economy is basically and fundamentally driven by net energy resources. Profound thermodynamic first principles absolutely and positively guarantee this.

Here's one definition that can end up both handy and remarkably useful...

DOLLAR — A voucher currently exchangeable for the personal use and control of ten kilowatt hours of electrical energy or thirty kilowatt hours of gasoline.

You'll vote for this definition every time you pay your power bill or every time you make a withdrawal from the ATM pump at your nearby *Texaco* bank. It is thus both a valid and a useful concept to think of *"using dollars"* as *"spending gasoline"*.

There are normally three primary components to any energy delivery system: The cost of the feedstock, the cost of the delivery infrastructure, and the cost of the finance amortization. Typically the latter two will dominate. Very often, a "free" feedstock will still lead to a very expensive system. One that is quite likely noncompetitive.

An *energy source* is a substance or a system that can be capable of delivering *net* kilowatt hours of energy to the on-the-books economy. Gasoline is a net energy source because it takes something like one quart of old gasoline to deliver one gallon of new gasoline. Note that it does not matter how many eons some swamp labored forth mightily to produce the gasoline. It is only the present on-the-books equivalent cash flow that counts.

An *energy carrier* is some means of moving energy from one location to another. Batteries, flywheels, utility pumped storage and terrestrial hydrogen are typical.

They are carriers or "energy transfer systems" because you first have to "fill" them with energy before you can "empty" them. Without fail, *all energy carriers consume significantly more existing old energy than they can return as new*. An energy carrier is inherently a "pollution amplifier" that will *magnify* the pollution created by its underlying sources. It is ludicrous to claim that terrestrial hydrogen is in any way "nonpolluting".

An *energy sink* is any means that consumes more "old" energy than it returns as new. To date, solar photovoltaic PV systems remain a net energy sink and a net destroyer of gasoline because PV has in totality consumed far more old energy than it has yet to deliver as new. If your solar panel is generating two cents worth of electricity a day and the interest cost is three cents a day, you have a net energy sink. The longer you run it, the more gasoline it wastes.

Corn ethanol under American farm conditions appears to be a net energy sink because *independent studies* tell us you have to put more old energy in than you get back as new. A strong case can be made that ethanol is simply an outrageous twelve billion dollar federal vote buying scam. Current subsidy free US corn-ethanol-as-energy production remains at zero. While ethanol under subsistence *bagasse* (sugarcane residue) conditions is theoretically capable of becoming a net energy source, Brazil nearly bankrupted themselves in a futile attempt to verify this theory.

Depending upon who is doing the accounting, on the decommissioning and storage realities, and how the next four or five Chernobyls are going to pan out, I strongly feel that nuclear power will end up to be something between a staggering energy sink and a minor and temporary source that clearly was not worth the monumental hassles.

Wind power can be a net energy source depending upon location and the present investment versus payout ratios. Wind gets tricky in a hurry since the recoverable energy is proportional to the *cube* of wind speed. Leaving scant room between effective and destructive velocities. In most locales, wind will only provide a tiny fraction of energy needs. As an example, *all* of California's present wind production can only meet something like ten percent of Connecticut's energy needs.

More on this at this superb *Energy Advocate* website. Similarly, hydroelectric is often a potent net energy source, but only of sorely limited capabilities. The trend lately is towards tearing down dams rather than building new ones.

Energy Density

Two important methods of fairly comparing the value of energy delivery schemes are to ask *"How big is it?"* and *"How much does it weigh?"*

Although many measurement schemes exist, I feel the fairest and most general are a *volumetric* energy density in *watthours per liter* and a *gravimetric* energy density in *watthours per kilogram*. There are roughly four liters in a gallon, or 3.785 to be more precise.

Here are a few common...

ENERGY DENSITY COMPARISONS

Gasoline	9000 Wh/l	13,500 Wh/Kg
LNG	7216 Wh/l	12,100 Wh/Kg
Propane	6600 Wh/l	13,900 Wh/Kg
Ethanol	6100 WH/l	7,850 Wh/Kg
Liquid H2	2600 Wh/l	39,000* Wh/Kg
150 Bar H2	405 WH/l	39,000* Wh/Kg
Lithium	250 Wh/l	350 Wh/Kg
Flywheel	210 Wh/l	120 Wh/Kg
Liquid N2	65 Wh/l	55 Wh/Kg
Lead Acid	40 Wh/l	25 Wh/Kg
Compr Air	17 Wh/l	34 Wh/Kg
STP H2	2.7 Wh/l	39,000* Wh/Kg

*=uncontained

Please note that it does not matter in the least whether you are "for" or "against" gasoline or whether you like it or hate it. Gasoline (and diesel and hydrocarbon equivalents) are and likely will remain the de-factor standards of energy density comparisons at 9000 watthours per liter and 13,500 watthours per kilogram. Gasoline also currently defines acceptable standards of safety and convenience for most personal transport.

Serious competitors *must* approach parity.

We see that classic lead acid batteries are kinda pathetic at 40 watt hours per liter and 25 watt hours per kilogram. And that the best of newer lithium batteries are still getting beat out by gasoline by a factor of *thirty* or more.

For a rather basic reason, lithium is likely to "win" the battery race. Most electrochemical reactions only involve one or two outer shell electrons. The fewer neutrons and protons, the higher the gravimetric energy density. Thus favoring low numbered elements.

Flywheels for bulk energy storage ain't gonna happen because of the outrageously large motors needed for fast windup. Except for a possible niche or two. They already have largely been eclipsed by newer battery technology.

Elemental Hydrogen gives us a curious mix of energy density values. At first glance, its 39,000 wh/kg seem to be

an outstanding advantage. And it is for deep space apps.

At a closer look, this figure is virtually meaningless for most terrestrial apps. Why? First, because a 3X increase in gasoline gravimetric energy density would not end up all that big of a deal for most end users. Possibly saving 26 pounds or so of average weight in an average vehicle.

But much more important, you do have to consider the *contained* weight of an energy delivery system. A gas tank adds relatively little weight to the gasoline it contains. But it is enormously unlikely you would be able to contain an equivalent 13 pounds of hydrogen in any 26 pound tank. Thus, the real-world contained energy density of hydrogen by weight is typically a lot *worse* than gasoline.

On the volumetric side, the hydrogen news is worse than all bad. STP hydrogen gas is laughingly pathetic. 2.7 watt hours per liter recoverable as electricity, or 3.3 watt hours per liter as heat. After compression and containment losses, ultra cold cryogenic liquid hydrogen has around one-fifth the energy density of gasoline.

Curiously, *there is more hydrogen in one gallon of gasoline than there is in a gallon of liquid hydrogen*. This happens because gasoline is denser by more than its hydrogen mole fraction.

Ultra high pressure hydrogen gas has been proposed, but it still has poor energy density. Besides obvious and serious safety issues. As a fireman, I can assure you that crawling around in a flashed over burning building that is about to collapse is not nearly as scary as filling a small air bottle. In the US, 150 Bar hydrogen gets locally delivered using tube trailers, but cryogenic liquid hydrogen gets mandated for longer distances.

The high pressure hydrogen proponents are most likely using this as a temporary "place marker", letting them do ongoing research on a workable platform. But any extreme pressure hydrogen (aka "terrorist bombs") turned loose on the general public is utterly insane.

To quote an old farmer that I once knew "Such thinking comes from long hours in the outhouse alone."

Liquid nitrogen cars can offer the performance of lead acid battery ones for a fraction of the cost and complexity. These make great student projects as *this site* and *this site* show us. These will likely remain "Gee Whiz" projects.

There's been some web noise lately over compressed air vehicles. It is obvious they never talked to anyone in the fire service who dearly would love to use compressed air for such tasks as rescue saws, spreaders, rapid cutters, PPV vent fans, and such. But are unable to do so because of the lousy energy density and appalling inefficiency of compressed air. Despite years of careful engineering.

Because of the law of diminishing returns, typical fire departments have elected not to go from 150 to 300 Bar on their airpack systems. Higher pressures are beyond the pale.

Thermodynamics

Thermodynamics started out as the study of heat engines, but the fundamental thermo laws have long since turned into the centralmost tenets of everything we know about physics and chemistry. Without exception, *all* energy and alternate energy sources *must* rigorously obey these laws.

The three most important rules tell us that you cannot get more energy back from any non-nuclear and reasonable sized closed system process than you first put in; that you cannot get nearly as much mechanical energy back from a heat engine as you input as heat; and that when left to themselves, systems tend to less and less useful forms in a never ending quest to maximize their *entropy*. No matter how it is used in what way, virtually all energy is certain to ultimately end up as useless low grade heat.

Paraphrased, you cannot win, you cannot break even, and everything eventually goes to hell in a handbasket.

Two very significant thermo concepts are the *Carnot Efficiency* and *reversibility*. A heat engine has to waste a lot of heat energy to produce a little mechanical energy. The best you can do in theory is the Carnot Limit set by the ratio of input and output absolute temperatures. For this reason most low delta-T heat recovery schemes are doomed to failure. Even if your scheme can be *replaced* by a heat engine, the limit still strictly applies.

For you can do no better.

A reversible process kicks off no waste heat. Examples are *isothermal* ones that take place at constant temperature and *adiabatic* ones that neither add nor remove heat. The quest for reversibility is an elusive goal. And a must any time decent efficiencies are needed.

Ferinstance, a *Tesla Turbine demands* irreversibility to operate at all. Because of maintaining friction shear forces in a viscous fluid. Although superb for pumping live fish or frozen chickens, they are a noncompetitive nonstarter for any efficiency sensitive turbine application.

I have posted a tutorial review of thermodynamics up as *HACK64.PDF* in my *Hardware Hacker* library. A good older text is Sandforth's *Heat Engines*.

Efficiency and Efficacy

Efficiency is how much you get back compared to what you started with. Often expressed as a percentage. When your output energy is somehow different from your input, then *efficacy* is a more correct but less used term.

But there are different ways to measure efficiency. If you go into the lab and measure the useful raw watthours out versus the raw watthours in, you are measuring the *raw efficiency*. If you consider all the total direct costs of the system and its labor and acquisition and amortization, you are measuring the *fully burdened efficiency*. Finally, the *societal efficiency* would throw in such externalities as pollution, quality of life considerations, renewability, wars, sustainability, politics, and such.

Thermodynamics guarantees that no closed system can be "overunity" or have an efficiency above 100%. At least when all inputs are fully accounted for. Ferinstance, my Pathfinder easily gets a thousand miles to the gallon. Of windshield washer fluid.

Energy sinks can have negative efficiencies.

Some current efficiency figures of interest: The latest of *utility power plants* are nearing 60 percent by combined cycling. Auto ICE engines are in the low thirties but are now improving dramatically. Surprisingly, most air motors are only 29% efficient or so. Solar pv panels rarely do better than ten percent at their terminals.

And much less at system output. *Before* amortization.

Heat pumps can output more heat energy than they are input as electrical or mechanical energy, but you have to fully include *both* the energy forms when doing any true thermodynamic accounting. The COP or *coefficient of*

performance of a heat pump is a ratio of the heat energy you move to the input electrical energy. A COP of six is easily reached if the delta-T is reasonably low. The SEER or *seasonal energy efficiency rating* is an alternative to a COP which can take your degree days of need into account. Air conditioning SEER's of 12 are common with newer scroll compressors. These are increasable to the 15 range with intelligent and variable speed air handling.

A solid state *Peltier Cooler* typically has a COP of 0.2 or less. Today's models are useless at higher power levels (anything over a few watts) because their delta-T across their heatsinks easily exceeds their net cooling.

Vortex Coolers also have pitiful COP's of 0.3 or so, but at least the waste heat is across the room rather than in the worst possible place.

Measuring raw efficiency can be enormously difficult. Any time unusual electrical waveforms are involved, *true rms measurements* are an absolute must. Only recently have lower cost power measurement chips of decent *Crest Factors* even become available. So you can safely assume most earlier low budget work was flat out wrong.

All sorts of rude surprises evolve if you are measuring something you're not familiar with. Ferinstance, accurately measuring the hydrogen from an electrolysizer is wildly difficult. There's water vapor from dielectric heating, other gases, and unknown temperatures and pressures.

Outrageous "overunity" claims have long been made for heaters that stir oil to cavitation. Whose explanation is most likely just the inability to properly measure chaotic or rapidly fluctuating rotary power.

Exergy

"Energy can neither be created nor destroyed" is a nice motto. And has a certain ring to it. But it only tells you a misleading fraction of the total story. Say you have a room and a kitchen match. Strike the match. The energy is the room was exactly the same before and after the match was struck. So, why would anyone prefer an unstruck match instead of a slightly warmer room?

It turns out that some kilowatt hours of energy are worth considerably more than others. Why? Because of a very little known thermodynamic concept called *exergy*.

Exergy is a measure of energy *quality*.

This *Thermodynamic Economics* website tells us that exergy has a precise definition. With liquid fuels, exergy is related to a property called the *Gibbs Free Energy*. Exergy measures the *reversibly recoverable* energy fraction.

Real-world economics gives you a looser definition of exergy. By asking "how much is this stuff really worth?"

Ferinstance, electricity is just about the highest exergy stuff there is, as you can so conveniently move it or very efficiently convert it into other energy forms. Electricity often has a retail value near ten cents per kilowatt hour.

Heat (especially at low temperature differentials) is much lower in exergy because of its gross inconvenience and its inefficiency in conversion to other forms. Because of this, those kilowatt hours in gasoline have a retail exergy value around three cents per kilowatt hour. Thus, a kilowatt hour of gasoline will usually be worth less than *one third* of a kilowatt hour of on-grid electricity.

Home electrical resistance heating gives a good example of the problems you get into with avoidable exergy drops. Using resistance heat, you get *one* low value heat kilowatt hour of energy back for each high value electrical kilowatt hour input. Sell the electricity and buy natural gas, and you can get *three* kilowatt hours of heat energy back for each electrical kilowatt hour input. Better yet, run a heat engine backwards as a heat pump, and you can get *five* kwh of heat returned for each electrical kwh input.

Chemical engineers go far out of their way to design processes that minimize loss of exergy. Any solar-to-fuel system which is to succeed absolutely, emphatically, and positively *must* avoid any large mid-process exergy drops. Because such drops can easily force any renewable and sustainable resource into becoming a net energy sink.

Note that a process can appear to be fairly efficient and still lose so much exergy as to be useless. Electrolysis with its less than 1:1 conversion of high value kilowatt hours into low value kilowatt hours is an example.

Hydrogen Realities

At first glance, hydrogen would seem to have some things going for it as an alternate energy resource. Hydrogen burned in oxygen forms only water vapor. Which is a relatively benign pollutant. But when hydrogen is burned in air, more noxious oxides of nitrogen can also result.

Hydrogen can directly generate electricity in a fuel cell. While replacing Carnot heat engine restrictions with a new set of efficiency limitations. The modest (5%) hydrogen injection into an otherwise conventional ICE appears to significantly improve performance. Although it is not yet clear whether net energy gains can result or how well this can be integrated with ongoing ICE improvements.

The first really big negative is that *no large source of terrestrial hydrogen exists*. While there a few remote wells that do produce a few percent of hydrogen, this gets normally burned off as an unexploitable waste product. Instead, hydrogen is normally produced commercially by the reformation of methane. Here on earth, *hydrogen is only an energy carrier that inefficiently transports some other source of net energy*. As we'll shortly see, electrolysis is not normally a useful means of producing bulk hydrogen energy because of its staggering loss of exergy. Especially from an on-grid or pv source.

A second negative is that the energy density of hydrogen is very low. As we have seen, the *contained* gravimetric density is usually lower than gasoline, while the volumetric density is a joke with up to a 3000:1 difference.

A third really big negative is that *no personal vehicle practical means of storing hydrogen is known today*. Compressed gas has far too little energy density, besides being a deadly terrorist bomb. Cryogenics are inefficient and expensive, besides offering only a fraction of gasoline density. And (because of a necessary boiloff) only being useful for shorter term storage. There are also frostbite and blindness safety issues. Hydrides remain expensive, low density, cumbersome, and of low lifetimes. Sadly, early enthusiasm over *carbon nanotube* storage has waned due to failures to replicate early spectacular claims.

Other negatives do include hydrogen having one of the widest explosive ranges known. Hydrogen flames have very low visibility, owing to emissivity mostly in the ultraviolet. On a hydrogen hazmat rollover, firemen sometimes use a pike pole with a rag tied onto it to "joust" with the flame

front. While it is very difficult to release all of the energy in a gasoline tank at once, doing so with a hydrogen release can be trivial. As a trained hazmat professional, I strongly feel that present "safety demos" are a laughable scam. But one that will spectacularly take care of itself.

The very real hydrogen safety issues get compounded by perceived "Hindenburg" lore. Hydrogen also lacks odorants or colorants and tends to rot most metals through a process called *embrittlement*.

Hydrogen certainly should get thoroughly studied and evaluated because it will likely play a significant supporting role in the internal reactions in future transportation and home energy solutions. But I do not see any elemental "hydrogen economy" emerging as such.

Even if hydrogen is still number one on the charts.

Nor do I see any point in building your own home solar sourced and hydrogen powered ICE lawn mower. A recent realistic numbers check showed a 40 watt surplus PV solar panel could let you mow your lawn once every 300 days. Besides, of course, being a monumental waste of gasoline due to its being a net energy sink.

Such stunts as a Chicago hydrogen bus demo that was trucking its hydrogen in from Pittsburgh certainly do not aide the cause much.

I eventually see a solar to liquid hydrocarbon conversion process "winning" the sustainable and renewable energy "war". One that is carbon neutral rather than carbon free. One that could use a largely unmodified infrastructure and delivery process. And one that most definitely will not use any staggering mid-process exergy losses.

This "carbon neutral" process would remove as much carbon from the air as it later returns. "Carbon free" has the problems that carbon contributes very significant energy to most hydrocarbon fuels and seems to be a key to making them convenient room temperature liquids.

I feel the conversion keys will be some magic chemicals called *metalloradicals*, which are the secret ingredient to normal plant photosynthesis. Hoganson and Babcock's *A Metalloradical Mechanism for the Generation of Oxygen from Water in Photosynthesis* is a key early paper. As found in *Science* for September 26, 1997.

Electrolysis Fantasies

Water is an *ash*. By chemical energetics, it is thus about the *worst* place to look for a bulk hydrogen source.

At first glance, it seems easy enough to use *electrolysis* to split water into its oxygen and hydrogen components. Just apply any low dc current for bubble, bubble, toil and trouble. Full details first appeared by Michael Faraday over a century ago. And are easily found today in Britannica's *Great Books #45*.

Electrolysis is certainly useful for cooling generators or petrochemical refining or precision low energy torches or lifting research balloons or making fat pretty but deadly. But nearly all of these use *unstored* hydrogen-on-demand and do value their hydrogen *much higher* than by its meager energy content.

As we've seen, retail electricity is worth about ten cents per kilowatt hour. Lower exergy gasoline is worth three cents per kilowatt hour. Your value of raw unprocessed hydrogen is not well established, but we do know it will certainly be a lot less than gasoline today. Because it has not yet impacted gasoline in any significant way. I feel 0.8 cents per raw hydrogen kilowatt hour can be a reasonable ballpark estimate.

In a typical situation, electrolysis takes two or more kilowatt hours of electricity worth ten cents each and converts them into one or fewer kilowatt hours of hydrogen worth less than a penny each.

And that is *before* any fully burdened cost accounting, amortization, storage or processing. Thus...

> *Electrolysis for bulk hydrogen energy is pretty much the same as 1:1 converting US dollars into Mexican Pesos.*

At its very best, electrolysis introduces a staggering loss of exergy that dramatically reduces the quantity and value of transformed kilowatt hours of energy. *Electrolysis is thus wildly unsuitable when driven from high value electrical sources such as retail grid electricity or any small scale photovoltaics.*

If you have electricity, sell the electricity, buy some methane, and reform the methane. It is a lot cheaper and throws away a lot less exergy.

This is remarkably comparable to our earlier electrical resistance heat example. Where your best solution involves converting a few higher value kilowatt hours into *more* lower value ones. Rather than fewer.

Even if you have a renewable and sustainable source of ultra low cost electricity, electrolysis can still easily convert it back down into a net energy sink.

Individuals making their own "homebrew" hydrogen by electrolysis face other rude surprises. For openers, some to much of the produced "gas" may end up water vapor from dielectric heating. Safety issues are largely unappreciated and easily lead to *Darwin Awards*.

But the really big gotcha is trying to use stainless steel rather than costly platinized platinum electrodes. Because of the *hydrogen overvoltage of iron* found in most any electrochem textbook, and because of the dead-wrong *low energy passivated surface*, stainless slashes your possible efficiency *by one-half* or greater.

The emerging alternates to electrolysis? Direct *solar to hydrogen* has been demonstrated by several researchers, starting with an April 17, 1998 issue of *Science*.

Excessively annoyed *pond scum* also can apparently produce hydrogen.

Fuel Cells

A fuel cell is just an electrolysizer run backwards. You input hydrogen and oxygen, and output electricity, water, and waste heat. These are potentially quiet, small, and have few moving parts. They avoid Carnot efficiency limitations at the price of other restrictions. Fuel cells can be classified by their end use as utility, laptop, or automotive.

Power utility fuel cells have long been available. They are propane or natural gas powered and will be large and stationary. They're best used for emergency power backup systems or for *Cogeneration* apps where the waste heat can be put to good use. Hospitals, laundries, and industrial process heat are good candidates. *Power Engineering* magazine is also a good source for ads and tech info.

The laptop market should be the next to emerge. Where users would be most happy to pay ten times the cost and

accept one-tenth the energy density of automotive needs. Besides being an instant market (Circuit City is ready when you are) And largely free of infrastructure, regulation, or political hassles. Competitors include improved or cheaper batteries, and miniature *MEMS D-Cell turbines*.

The automotive fuel cell market still faces some severe problems. These do include membrane cost, fragility, and lifetimes. Plus unresolved fuel reformation (the fuel really has to want to reform) and storage issues.

The big lie over auto fuel cells is that they can be two or three times as efficient as an internal combustion engine. A more truthful statement would be "automotive fuel cells do appear to have the potential of a modest but significant advantage over ICE efficiency at some future date." I'd personally predict ICE at 38% and transportation fuel cells at 42% within a decade.

Why? Firstoff, because all hydrogen fuel cells start with a theoretical 83 percent efficiency. Because an electrolysizer can be one-sixth endothermic, reversing it has to end up a minimum of one-sixth exothermic. Motor (90%), controller (85%) and wiring (97%) efficiencies cut this further. Worst yet, energy is required for reformation, and the process will reduce or eliminate entirely the significant carbon energy fraction of the fuel. Finally, amortization and replacement costs are likely to remain quite high.

On the other side of the fence, ICE efficiency is currently improving at one percent per year, and additional gains can be shortly expected. These should happen by way of 42 volt electrics, drive by wire, electric valves, by on-demand water pumps, on-demand steering, ceramic liners, variable compression, narrower speed operation, multi stage lean burn, CV transmissions, bottom cycling, exhaust recovery, fully integrated alternator/starter/regeneration, six cycle operation, hybridization, and idle shutdown. The *SAE* is a good resource here.

Additional fuel cell resources and links are found *here* and *here*.

Photovoltaics

Photovoltaic "pv" solar cells are wildly successful when used on solar power calculators. This enormously large market is driven by people who are happy as a clam paying *five hundred dollars per kilowatt hour* for all of their electricity. A figure gotten by taking that fifty cent retail value of the cells extended over the total actual calculator use lifetime energy consumption of about one watthour.

To date, on a historic and totally system wide basis, *not one net watthour of solar pv electricity has ever been produced*. Solar pv thus remains a net energy sink.

Only recently have studies been made to find out how much energy it takes to actually build a panel. While some the latest of pv panels can in fact return you five or more times their construction energy, this is normally far too little to produce a net energy gain when it is full burden amortized over complete synchronously inverted utility buyback systems. Also, the 5X breakeven ignores panels that are unsold or not completely utilized to 100 percent capacity over their ultimate lifetimes. Underutilized panels remain net energy sinks. Obviously, not every installation can exactly draw all available power all the time.

Detailed descriptions of solar PV projects do show up regularly in *Home Power* magazine.

A recent issue (#90) described a typical 2400 watt solar grid interconnected system that produced just under 5 kwh a day at a materials and labor cost of $20,000.00. In the real world, they verified you get a lot less than 2400 watts out of 2400 watt panels because of the panel aging, solar site insolation, tracking angles, the days of available sunshine, dust, cloud cover, wiring loss, and synchronous inverter efficiency. Produced power was worth about fifty cents per day if used on site, or twenty five cents per day if bought back by the utility. When state regulations permit, power utilities sell retail but buy wholesale at their avoided cost.

The only tiny oint in the flyment is that even at a *one percent* simple interest rate, servicing the debt costs more than fifty cents a day. Thus, their system is a net destroyer of gasoline. Using up more net old energy than returned.

I felt their labor figures at $700.00 were unrealistically low for creating this system from the ground up. In this example system, even if the panels were obtained at zero cost, an interest rate above three percent would guarantee a net energy sink.

Today, solar pv installations are certainly quite useful for remote "Uh—compared to what?" applications. Such as mountaintop communication repeaters or ranch solar livestock water pumping. Or where subsidies such as the outlandish cost of installing new utility poles can justify them. Or as "Golly Gee Mister Science!" gimmick options in upscale housing developments.

The profits, of course, go to the home builder who just got a $60,000 higher selling price for a third that cost in off-the-shelf parts. And not to the epsilon minus buyer who was newly saddled with really, really dumb long term financing of a huge energy sink.

But by no stretch of the imagination can solar pv ever be considered renewable or sustainable energy today.

I definitely see home-sized solar to electric converters reaching utility grid energy parity breakeven, possibly in a decade. The more distant actual net energy breakeven will probably happen *eight years after the fully burdened grid utility equivalent costs drop under eight cents per kilowatt hour*. Naturally, once parity is in sight, zillions of dollars will be thrown at solar pv, thus creating a horrendous but hopefully brief energy sink glitch. After which renewability and sustainability may emerge.

You will know when this happens by (a) pv being used to fully produce pv, and (b) by aisle 13 at *Wal-Mart* being clogged with 110 vac, 1 kw plug-and-go home panels.

But for several reasons, I do not see conventional silicon pv *ever* reaching fully burdened energy breakeven. At least not without a lot of outside help. First, because there is a fundamental Carnot-like efficiency limit which prevents these cells from significantly exceeding a theoretical 30 percent or so of raw efficiency.

Silicon offers a *bandgap energy* of 1.12 electron volts, equivalent to a 1106 nanometer wavelength in the near infrared. Energy of this exact wavelength can be efficiently converted. Longer wavelengths are ignored and lost as low grade heat. As is any "spare change" from higher energy wavelengths above this precise energy quanta level. Since solar energy has a broad spectrum, most of it unavoidably gets converted to heat by an ordinary silicon pv cell.

Incoming solar energy is diffuse. Should you get under a six percent system efficiency, the system will *never* pay for

itself. Why? Because the system and its land and labor and amortization get way too big way too fast. For this reason, capture of the 1000 or so watts per square meter maximum insolation as efficiently as possible is an a must.

Second, because panels only represent a fraction of the total installed cost. And because breakeven figures beyond three years are scary using any technology that is likely to be soon replaced by a far better solution.

The third problem is one of silicon supply and demand. To date, the solar panel makers largely use "scrap" silicon from the integrated circuit manufacturers. The newest ic process produce far less scrap and the solar pv demand is already way beyond what is available. A severe materials crunch is likely to occur shortly.

What do I think will emerge as a winner?

There have been tremendous advances in *MEMS* or ultra small structures which newly make direct broadband solar antenna-rectifiers possible. Having very high theoretical efficiencies. Literally a solar "crystal set". Alvin Marks and his *Lumeloid* and *Lepcon* concepts has long been a pioneer in this research area. Other possibilities include our previously mentioned metalloradicals getting interrupted mid process, grabbing the electrons and outputting them as electricity. As can similar dye molecules or other pseudo photosynthetic reactions.

Some recent discoveries by *Sandia Labs* do show some curious infrared energy trapping upconverters that may impact everything from ordinary light bulbs to silicon pv.

They are called "tungsten photonic lattices".

My own take

Amory Lovins has long been a proponent of *negawatts*, or energy gain from conservation and better efficiency.

My own research efforts have also been in the energy efficiency area. I have come up with my new and unique method to substantially improve the efficiency of larger motors, automotive drives, and solar converters. My *Magic Sinewaves* use far fewer switching events to produce low distortion, high power waveforms. Additional tech details can be *found here*.

For more help

Elsevier does seem to be the leading publisher of energy related journals. Such as...

Applied Energy
Biomass & Bioenergy
Energy
Energy Conversion & Management
Fuel & Energy Abstracts
Fuel Cells Bulletin
International Journal of Hydrogen Energy
Journal of Wind Engineering
Ocean Engineering
Photovoltaics Bulletin
Solar Energy Materials & Solar Cells
Sustainable Energy Review

Besides zillions of additional rather pricey journals and books, *Solar Energy* is also published by Elsevier for the *International Solar Energy Society*. Your really heavy stuff will come down in *Science* or *Nature* magazines. The *Electric Power Research Institute* also offers interesting pubs. I also like *Battery Power Products & Technology*.

Most of the usual web search engines easily find energy info. Especially *Google*, *Hotbot*, and all the similar *search engine links* on my *Guru's Lair* home page.

There are a number of newsgroups of energy interest. Three of these include *sci.energy*,*sci.energy.hydrogen*, and *alt.energy.homepower*

I've gathered together a collection of recommended energy books on our *Book Access* pages. The categories include batteries, carbon nanotubes, electrochemistry, fuel cells, electric car, hybrid car, hydrogen, thermodynamics, and wind energy.

As previously mentioned, tutorials and links to major hydrogen resources appear on our *Its a Gas* library page. Additional tech content might also show up on our new *GuruGram* library page. *Magic Sinewaves* and *InfoPack Consulting* also have their own pages.

As always, your support as *surplus bargain* seekers, as *eBay auction* buyers, *Banner Advertisers*, or joining our *Synergetics Partners* is always welcome.

Let's hear from you. ✦

Microcomputer pioneer and guru Don Lancaster is the author of *35 books and countless articles. Don maintains a US technical helpline you will find at (928) 428-4073, besides offering his own books, reprints and consulting services.*

Don also offers surplus bargains found on eBay and on his Bargain Pages .

Don is also the webmaster of www.tinaja.com You can also reach Don at Synergetics, Box 809, Thatcher, AZ 85552. Or you can use email via don@tinaja.com